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Silicates

L. C. Lemox and Chas. N. Cos, Jr.

No. 2. The Design of a Low-Tension Switch-Board

Vernon T. Brigham

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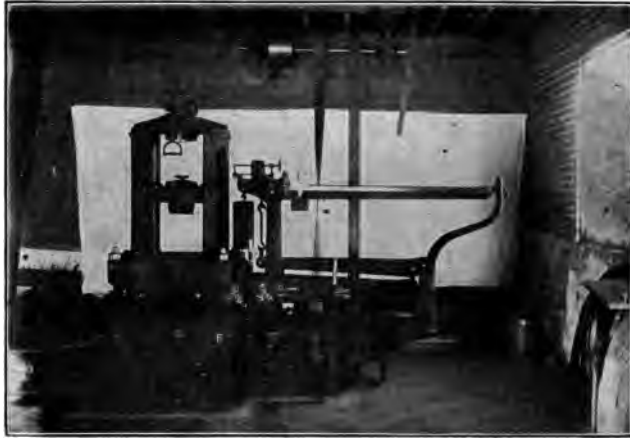
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THE FUSIBILITY AND FLUIDITY OF TITANIFEROUS SILICATES.*

BY L. C. LENNOX AND CHAS. N. COX, JR.

In several places in the United States are found large bodies of iron ore of high grade, but containing titanic acid in considerable amounts. This ore is not being mined at present, for there is a widespread prejudice among blast furnace men against ores containing titanic acid, on account of their supposed tendency to form accretions in the hearth.

Mr. A. J. Rossi, of New York, constructed a small blast furnace, and conducted quite an extensive series of experiments on the fusibility and fluidity of actual slag mixtures containing varying per cents of titanic acid. Mr. Rossi's general conclusions were that it was perfectly feasible to obtain mixtures in the blast furnace that would produce slags fully as fusible and fluid and in every way as satisfactory as those obtained when using ore free from titanic acid. He attributed the trouble caused by this substance, in the earlier days of iron manufacture in this country, to the ignorance of the blast furnace men in regard to the material that they were handling, rather than to the influence of the titanium. He thinks that the modern blast furnace man's fear of titanium-bearing ores is based almost entirely upon prejudice, because of the early mistakes in the methods of handling them.

In Vol. 33, of the Transactions of the American Institution of Mining Engineers, is an article written by Mr. Rossi, in which he states that, in making up slags for a titanium-bearing ore, the titanic acid (TiO_2) should enter in as so much silica (SiO_2), and all calculations should be made with this in view. In this article he gives the

*Submitted to the Faculty of the School of Engineering of Colorado College in June, 1906, in partial fulfillment of the requirements for the Degree of Bachelor of Science in Mining Engineering.

percentage composition of several slags which proved to be quite satisfactory, and which will appear later in this article as comparison tests. With these facts in view, it was decided to make a number of tests on titaniferous slag mixtures in order to verify Mr. Rossi's experiments, and thus perhaps interest those who are in a position to do some experimental work on a commercial scale.

Before attempting to outline the method of conducting these tests, it will be desirable to say something about the materials used in making up the slags. Of necessity the tests were conducted on a small scale, and so, with the exception of the limestone and rutile (which formed the source of titanic acid), the ingredients are chemically pure. Fortunately a limestone was obtained, quarried in the Garden of the Gods, which was, with the exception of .018 % Fe_2O_3 and .0018 % MgO , pure CaCO_3 . For the sake of simplifying the computations, it was called 99.98 % pure, and the Fe_2O_3 and MgO ignored. Considerable difficulty was found in obtaining a satisfactory analysis of the rutile. There was no difficulty in finding a good method for the determination of titanic acid in small quantities, but for a long time no satisfactory method was found for its determination in large quantities. Nearly a month was spent in trying different schemes before satisfactory results were obtained. Below is the method that was finally adopted, but the user of it will encounter much trouble, unless it is exactly followed:

Fuse .5 g. of rutile with 10 g. of potassium bisulphate. This fusion must be conducted with extreme care, to prevent spattering and creeping of the liquid mass onto the outside of the crucible. It should be made in a covered platinum crucible; started at a very low heat at first, and brought gradually to a higher and higher temperature, as the water of crystallization and sulphuric acid of the bisulphate are driven off, until the whole mass is in quiet fusion. At no time should the action be allowed to exceed a quiet simmer.

The mass is then allowed to cool, and 20 c.c. of sulphuric acid added and boiled gently until the melt is entirely dissolved. Allow it to cool again, and pour into a beaker containing about 300 c.c. of cold water; rinse

the crucible and cover thoroughly, and add the rinsings to the 300 c.c. in the beaker. Add to the solution a few drops of HCl and 50 c.c. of strong sulphurous acid, and stir until all the precipitate that will do so has dissolved; filter, wash the residue, dry, ignite, and weigh it as SiO_2 . This residue should be tested with hydrofluoric acid to make sure it does not contain any unfused matter.

To the filtrate add just enough ammonia to produce a permanent precipitate (more than this will render the precipitate very difficultly soluble in HCl). Re-dissolve it immediately with a few drops of HCl. Add 20 g. of sodium acetate in water solution (50 c.c. is a convenient bulk), and $\frac{1}{6}$ of the volume of the total solution of acetic acid (1.04 sp. gr.) and boil for five minutes. Filter, wash with about 200 c.c. of water containing a little acetic acid, dry, ignite, and weigh as TiO_2 . Treat the filtrate in the usual manner for the determination of Fe_2O_3 , Al_2O_3 , etc. The rutile was found to contain—

Titanic acid	91.32 %
Silica	4.7 %
FeO (ferrous oxide)	4.02 %
Total	100.04 %

This rutile was obtained from the American Rutile Company.

As there was no guide to follow in the matter of the types of mixtures to use, it was decided to test and compare the monosilicates, bisilicates, trisilicates, and sesquisilicates. As all metallurgists know, the meaning of these prefixes are simply that the ratio of the oxygen atoms in combination with the bases of the slags to the oxygen atoms in combination with the acid-forming elements are respectively 1:1, 1:2, 1:3, and 2:3; and are represented by the general formulæ, 2RO SiO_2 , RO SiO_2 , $2\text{RO } 3\text{SiO}_2$, and $4\text{RO } 3\text{SiO}_2$, respectively, where R represents any bivalent base or bases, or by $2\text{R}_2\text{O}_3 \ 3\text{SiO}_2$, $\text{R}_2\text{O}_3 \ 3\text{SiO}_2$, $2\text{R}_2\text{O}_3 \ 9\text{SiO}_2$, and $4\text{R}_2\text{O}_3 \ 9\text{SiO}_2$, respectively. In the calculations that follow, it has been assumed that TiO_2 may take the place of SiO_2 in these formulæ, and also that the bases in the slag divide themselves between

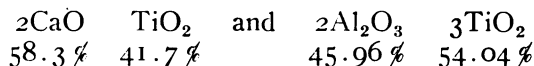
these two acids in proportion to the respective masses of the acids. It was decided to use slags containing the following percentages of titanous acid: $\frac{1}{2}$, 1, 3, 5, 7, 10, and 14. In these slags, alumina and calcium oxide, in the ratio of 1:3, was used. In those slags containing $\frac{1}{2}$ and 1 per cent. titanous acid, the c.p. TiO_2 was used; in the others, rutile, the analysis of which appears above.

Two other sets of slags were tested, viz: slags containing alumina, calcium oxide, and magnesia, in the ratio 12:33:3, and the following per cents. of titanous acid: 3, 7, and 14; and slags containing alumina and calcium oxide, in the ratio 1:4, and the following per cents. of TiO_2 : 1, 3, 5, 7, 10, and 14. The reasons for using these different ratios between the bases in the slags is that thus are obtained the per cents. of the bases usually found in ordinary blast furnace slags. In making up the slags, silica is used to supply all the acid not furnished by the titanous acid.

Below are given samples of the method of computing these slags, and also tables containing the results obtained from the remainder of the work:

EXAMPLE I. Computation of a monosilicate slag containing 1% TiO_2 , and alumina (Al_2O_3) and calcium oxide (CaO) in the ratio of 1:3.

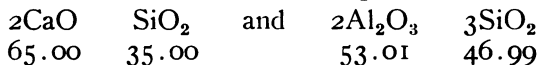
Satisfy the TiO_2 first: Write the formulæ for the titanates with their percentage composition directly below them—



Since the ratio between the CaO and Al_2O_3 is 3:1, there results: $(3 \times 58.3 \times 45.96) \div (58.3 + 3 \times 45.96) \times 100 = 40.974\%$ of CaO in this monotitanate slag. Dividing by 3, one has 13.658% of Al_2O_3 . Hence the TiO_2 amounts to 45.368%.

Now, TiO_2 forms but 1% of the ultimate slag, so the % of the above CaO in the ultimate slag = $40.974 \div 45.368 = .903\%$. This gives .301% of Al_2O_3 in the ultimate slag. The TiO_2 , CaO , and Al_2O_3 , together, amount to 2.20% of the ultimate slag; the remaining 97.80%

will be made up as silicate. As before, we derive the monosilicate formulæ and their compositions:



We have $(3 \times 65 \times 53.01) \div (65 + 3 \times 53.01) \times 100 = 46.14\%$ of CaO from the silicate. Hence we get 15.38% of Al_2O_3 and 38.48% of SiO_2 . But the monosilicate forms only 97.8% of the ultimate slag. So:

$$\begin{aligned} 97.8 \times 38.48 &= 37.63\% \text{ SiO}_2 \text{ in ultimate slag.} \\ 97.8 \times 15.38 + .301 &= 15.34\% \text{ Al}_2\text{O}_3 \text{ in ultimate slag.} \\ 97.8 \times 46.14 + .903 &= 46.02\% \text{ CaO in ultimate slag.} \\ &\underline{99.99\% \text{ Total.}} \end{aligned}$$

EXAMPLE II. Computation of a monosilicate slag containing 3% TiO_2 , and alumina and calcium oxide in the ratio of 1:3.

The formulæ and compositions above given will apply here as well, and so will not be rewritten.

Now, to obtain 3% TiO_2 :— $(3 \div 91.32) \times 100 = 3.28\%$ rutile must be used, and this contains: $3.28 \times .0402 = .132\%$ FeO.

This FeO is probably combined in rutile with both SiO_2 and TiO_2 , but in some unknown proportion. It was assumed that it would combine with the TiO_2 and SiO_2 in the inverse ratio of the atomic weights of Ti and Si; this assumption being based upon the theory that the greater the atomic weight of an element, the less its affinity for any other given element.

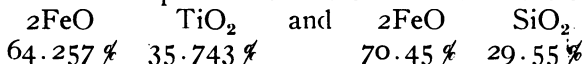
Then let x = the per cent. of FeO combined with SiO_2 , and y = the per cent. of FeO combined with TiO_2 , and taking the atomic weights of Ti and Si to be 48.1 and 28.4, respectively:

$$28.4/48.1 = y/x \text{ and } x + y = .132 \text{ or } x = .132 - y$$

(the % of FeO in 3.23 % rutile.)

Then $28.4/48.1 (.132 - y) = y$ or $.59 (.132) = y$ and $y = .049\%$ FeO combined with TiO_2 .

$x = .132 - y = .083\%$ FeO combined with SiO_2 . The formulæ and composition of these combinations are:



Then: $64.257:35.743 = .049:x$ and $x = .027\%$ TiO_2 combined with FeO .

Also: $70.45:29.55 = .083:x$ and $x = .033\%$ SiO_2 combined with FeO .

Now: $3 - .027 = 2.973\%$ uncombined TiO_2 .

In Example I., the preliminary monotitanate slag contained $.903\%$ CaO , and $.301\%$ Al_2O_3 , and 1% of TiO_2 . Hence we have:

$2.973 \times .903 = 2.684\%$ CaO in the monotitanate slag.

$2.973 \times .301 = .895\%$ Al_2O_3 in the monotitanate slag.

Adding these per cents:

2.684% CaO in the monotitanate slag.

$.895\%$ Al_2O_3 in the monotitanate slag.

$.027\%$ TiO_2 combined with FeO .

$.033\%$ SiO_2 combined with FeO .

$.132\%$ FeO in rutile. [monotitanate.

2.973% TiO_2 combined with CaO and Al_2O_3 in

6.744% Total.

Now: $100 - 6.744 = 93.256\%$ of monosilicate slag.

Hence, in the ultimate slag there are:

$93.26 \times .3848 + .033 = 35.917\%$ SiO_2

$93.26 \times .1538 + .895 = 15.238\%$ Al_2O_3

$93.26 \times .4614 + 2.684 = 45.713\%$ CaO

3.000% TiO_2

$.132\%$ FeO

100.000% Total

$35.917\% - .154\%$ (uncombined SiO_2 in 3.28% rutile)
 $= 35.763\%$, which is the amount of SiO_2 to be taken.

EXAMPLE III. Computation of a monosilicate slag containing 3% TiO_2 , and calcium oxide, alumina and magnesia in the ratio $33:12:3$.

The formulæ and composition of magnesia monotitanate and silicate are:

2MgO	SiO_2	and	2MgO	TiO_2
57.163%	42.837%		50.156%	49.844%

Using these per cents. in connection with the per cents.

of calcium titahate and silicate, given in Ex. I., and letting x, y, z signify ratios to be computed, we have:

$$58.3x : 45.96y : 50.156z = 11 : 4 : 1$$

$$41.7x + 54.04y + 49.844z = 2.973$$

where, by Ex. II., 2.973 signifies the % of TiO_2 to be combined with CaO, MgO, Al_2O_3 . Solving, $x = .0411$, $y = .019$, $z = .0043$. Hence there are, combined with TiO_2 , the following amounts: $58.3x = 2.396\%$ of CaO , $45.96y = .873\%$ of Al_2O_3 , $50.156z = .216\%$ of MgO . These three aggregate to 3.485% .

The following per cents. are partly taken from Example II.:

2.973 % TiO_2 combined with CaO, MgO, Al_2O_3 .

.027 % TiO_2 combined with FeO .

3.485 % CaO, MgO, Al_2O_3 , combined with TiO_2 .

.033 % SiO_2 combined with FeO .

.132 % FeO in 3.28 % rutile.

6.650 % Total.

Hence, $100 - 6.65 = 93.35\%$ = monosilicate slag.

We have the following equations:

$$65x^1 : 53.01y^1 : 57.16z^1 = 11 : 4 : 1.$$

$$x^1 + y^1 + z^1 = .9335.$$

Solving, $x^1 = .603$, $y^1 = .268$, $z^1 = .062$. The amount of SiO_2 is $35x^1 + 46.99y^1 + 42.84z^1 = 36.36\%$. We get also $CaO = 65x^1 = 39.20\%$, $Al_2O_3 = 53.01y^1 = 14.22\%$, $MgO = 57.16z^1 = 3.55\%$.

The ultimate slag is, therefore, as follows:

$$36.36 + .03 = 36.39\% SiO_2.$$

$$39.20 + 2.41 = 41.61\% CaO.$$

$$3.55 + .22 = 3.77\% MgO.$$

$$14.22 + .87 = 15.09\% Al_2O_3.$$

$$3.00\% TiO_2.$$

$$.13\% FeO.$$

99.99 % Total.

As in Example II., weigh out 3.28 % rutile and $36.39 - .15 = 36.24\%$ SiO_2 . Omit FeO .

EXAMPLE IV. Computation of monosilicate containing 1 % and 3 % TiO_2 , and alumina and lime in the ratio of 1:4.

The only difference that arises between these cases and Examples I. and II., respectively, is in the proportioning of the monosilicates, and monotitanates of alumina and lime.

In the following tables will be found the results of computations for sixty-four different slags. The column marked "% Rutile" is inserted for convenience in computing the weight of TiO_2 and FeO required for a charge, of any size, of the slag. All slags with .5 % or 1 % TiO_2 were made up from c.p. TiO_2 , and so no rutile was used.

In this set of tables there is added one containing four slag mixtures that, Mr. Rossi says, behave in a manner entirely satisfactory in a blast furnace. As FeO had to be added in all but one of these mixtures, we omitted the column marked "Rutile %." Since for these four slags the weight constituents are easily figured, little is gained by increasing the bulk of the table in this instance.

Also the composition of a regular blast furnace slag from the Jones & Laughlin Steel Company, of Pittsburg, Pa., and two of H. O. Hoffman's ferrous silicates, are entered in a table at the end, the first for the sake of having a standard of comparison to actual practice, and the two latter as checks on the accuracy of temperature readings.

TABLE NO I.*

RATIO OF LIME TO ALUMINA, 3:1.

Sili- cate.	TiO ₂ %	FeO %	SiO ₂ %	Al ₂ O ₃ %	CaO %	Rutile %	Slag No.
Mono.	.5	o	38	15	46	o	1
"	1	o	38	15	46	o	2
"	3	.132	36	15	46	3.28	3
"	5	.230	34	15	45	5.475	4
"	7	.307	32	15	45	7.665	5
"	10	.44	30	15	45	10.95	6
"	14	.644	26	15	44	15.331	7
Bi.	.5	o	55	11	34	o	8
"	1	o	54	11	34	o	9
"	3	.132	52	11	33	3.28	10
"	5	.230	51	11	33	5.475	11
"	7	.307	49	11	33	7.665	12
"	10	.44	46	11	32	10.95	13
"	14	.644	43	10	32	15.331	14
Tri.	.5	o	64	9	26	o	15
"	1	o	64	9	26	o	16
"	3	.132	62	8	26	3.28	17
"	5	.230	60	8	26	5.475	18
"	7	.307	58	8	26	7.665	19
"	10	.44	56	8	25	10.95	20
"	14	.644	52	8	25	15.331	21
Sesqui.	.5	o	47	13	39	o	22
"	1	o	47	13	39	o	23
"	3	.132	45	13	38	3.28	24
"	5	.230	44	13	38	5.475	25
"	7	.307	42	13	38	7.665	26
"	10	.44	39	12	38	10.95	27
"	14	.644	36	12	37	15.331	28

*In this table, as well as in the tables that follow, fractional parts of the percentages of SiO₂, Al₂O₃, and CaO, are omitted, and the nearest integral percentages are given.

TABLE NO. II.

RATIO OF MAGNESIA TO ALUMINA TO LIME, 3:12:33.

Sili- cate.	TiO ₂ %	FeO %	SiO ₂ %	MgO %	Al ₂ O ₃ %	CaO %	Rutile %	Slag No.
Mono.	3	.132	36	4	15	42	3.28	29
"	7	.307	33	4	15	41	7.665	30
"	14	.644	27	4	14	40	15.331	31
Bi.	3	.132	53	3	11	30	3.28	32
"	7	.307	50	3	10	29	7.665	33
"	14	.644	43	3	10	29	15.331	34
Tri.	3	.132	62	2	9	24	3.28	35
"	7	.307	59	2	8	23	7.665	36
"	14	.644	52	2	8	23	15.331	37
Sesqui.	3	.132	46	3	13	35	3.28	38
"	7	.307	42	3	12	35	7.665	39
"	14	.644	36	3	12	34	15.331	40

TABLE NO. III.

RATIO OF LIME TO ALUMINA, 4:1.

Sili- cate.	TiO ₂ %	FeO %	SiO ₂ %	Al ₂ O ₃ %	CaO %	Rutile %	Slag No.
Mono.	1	0	37	12	50	0	41
"	3	.132	35	12	49	3.28	42
"	5	.230	33	12	49	5.475	43
"	7	.307	32	12	49	7.665	44
"	10	.44	29	12	48	10.95	45
"	14	.644	26	12	47	15.331	46
Bi.	1	0	54	9	36	0	47
"	3	.132	52	9	36	3.28	48
"	5	.230	50	9	36	5.475	49
"	7	.307	48	9	35	7.665	50
"	10	.44	46	9	35	10.95	51
"	14	.644	42	8	35	15.331	52
Tri.	1	0	63	7	29	0	53
"	3	.132	61	7	28	3.28	54
"	5	.230	59	7	28	5.475	55
"	7	.307	58	7	28	7.665	56
"	10	.44	55	7	28	10.95	57
"	14	.644	51	7	27	15.331	58
Sesqui.	1	0	46	10	42	0	59
"	3	.132	45	10	42	3.28	60
"	5	.230	43	10	41	5.475	61
"	7	.307	41	10	41	7.665	62
"	10	.44	39	10	41	10.95	63
"	14	.644	35	10	40	15.331	64

TABLE NO. IV.

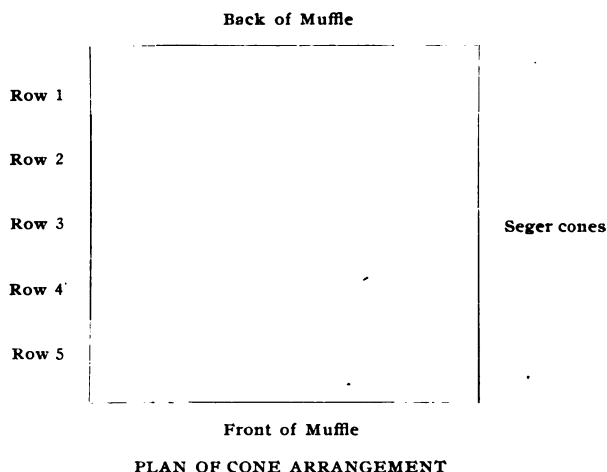
ROSSI SLAGS.

Slag No.	SiO ₂ %	TiO ₂ %	CaO %	MgO %	FeO %	Al ₂ O ₃ %	Total %
1.....	27.83	36.78	24.36	.36	1.85	9.18	99.76
2.....	26.72	25.11	25.81	5.99	3.46	11.86	98.95
3.....	15.90-17.50	34.38	22.10	9.70	4.30	11.23	97.61-99.21
4.....	.67	64.80	14.30	8.30	.90	10.50	99.47

TABLE NO. V.

Slag. Blast Furnace.	MgO	CaS	Al ₂ O ₃	SiO ₂	CaO	FeO	Melt'g Temp.
Hoffman No. 1.	2.20	3.82	15.80	34.10	41.70	.85	1290
Hoffman No. 2.				24.45	44.00	31.55	1310

The testing of these slags was conducted after two different methods, and with two distinct objects in view, namely, to find the fusing points of the mixtures, and to find the comparative fluidity of the slags at the temperature of 1410°C . For the fusing point tests, cones were employed, or, more properly, triangular pyramids, as near the size of Orton's Seger cones as they could be made. This method of making the fusion tests was adopted because it seemed to be the one finding most ready acceptance at the present time. At first, moulding them was tried in a wooden mould, by mixing the material (ground to pass a 100-mesh screen) with a sufficient quantity of a syrup made by boiling dextrin in water to make it into a stiff paste and then pressing this paste into the mould with a rammer made for the purpose. This method was unsatisfactory because of the sticking of the material to the mould, and resort was finally made to rolling the mixture out into thin rolls and cutting out the cones with a spatula. It was also found, after some trials, that gum tragacanth made a much preferable binding material. In the first place, when mixed with the slag, it formed a sort of dough, which was much easier to handle than the brash paste formed by adding dextrin. Then it was found that when the gum tragacanth cones were thoroughly dry, they could be placed immediately in a white-hot furnace without breaking, while the dextrin cones had to be heated up gradually, and the organic matter given time to burn off. To test these cones, they were stood in a dry fire-clay bed, which was placed in the furnace. The cones were arranged in rows, with a row of Seger cones across the middle of the bed.



The above figure shows the arrangement of the slag and Seger cones in the furnace. Row 2 was usually the hottest part of the muffle, and the row of Seger occupied an average between Row 2 and Row 5, which is the coolest row. In making up the bed for a second test, the slag cones—Rows 4 and 5—were interchanged with those in Rows 1 and 2, so that by averaging the results obtained for any slag, no great error, due to location in furnace, could enter in.

In this manner eight to twenty cones were tested at once. Six cones of each slag were made and run two at a time, so as to eliminate as far as possible any variations in the temperature in the different parts of the furnace, the slags in the front of the muffle in one test being placed in the rear in the second test. The fluidity tests were made first in nickel crucibles, but it was found impossible to keep the atmosphere sufficiently reducing to prevent their burning through. Platinum ware was too expensive, so it was decided to use the ordinary fire-clay crucible by first lining it with the mixture that was to be fused in it, and then glazing it by preliminary heating. This method gave excellent results. In making these tests, four of the glazed crucibles were placed with their charges of twenty grams each in the furnace, and a No.

14 Seger cone in their midst. The temperature was then raised until the cone bent over, and a few minutes allowed for the mass in the crucible to become quiet, when it was removed from the furnace and immediately poured on a hot inclined slab. The tables later on will give the result of these tests.

The manner of noting the temperature of the fusion tests on the silicate cones was to watch through a peep-hole in the furnace door. The temperature of fusion of any particular slag was told by noticing what Seger cone was going down when the slag cone bent over. As shown later by the Fusibility Tests, the range of fusing points was within the limits of No. 7 (1270°C) to No. 11 (1350°C) Seger. It was also noted that the slag cones bent much more rapidly than the Segers, when they once started—so much so, in fact, that when the cones were put into the furnace without first cooling considerably, some difficulty was experienced in judging their fusion points by the Segers. In these tests, Edward Orton, Jr.'s, cones were used in reading the temperatures. At this point it may be well to state that throughout the fusion tests, the method set forth by H. O. Hoffman, in his article entitled, "Temperatures of Formation of Various Silicates," (Vol. 29, Trans. Am. Inst. of Mining Engineers,) was followed.

At the outset of the work, it was expected to make use of a Le Chatelier pyrometer instead of the Seger cones, but the only instrument at hand had the end of the porcelain tube broken off, so that the wires were exposed to the gases of the muffle. It was found that after the pyrometer had remained in the furnace for a little time, its readings would go down, while the Seger cones told that the furnace was as hot as ever. Hence it was necessary to abandon the use of the pyrometer.

To obtain the temperature required for the tests, one of the regular assay furnaces in the laboratory was used. These furnaces have two muffles, one above the other. The upper muffle was removed so that this door might be used for packing fuel around the lower one. Artificial draft was produced by a small centrifugal fan, set up and connected to an electric motor. The fan was connected

up with four-inch pipe and the air blast conducted to the ash pit of the furnace. A hood was made to fit into the opening of the ash door, with a hole in the hood for the air pipe to pass through. In less than half an hour a temperature of 1500°C . could be reached. In keeping the furnace at a temperature of even 1400°C ., for some time, the fire-brick supports under the muffles would melt out. Much damage was done to the muffles in replacing the bricks, so that the muffles themselves were short lived, and much delay and many shut-downs were caused on this account. For this reason it was found impossible to perform as many experiments as were desirable.

The data that follow on Fusibility and Fluidity need but little further explanation, but it may be well to say that a number of tests were made at first with the cones, which were so unsatisfactory that the results were not entered in the tables. Instead of giving the temperature readings in terms of the Seger cones, they have been translated into $^{\circ}\text{C}$. It should be borne in mind that the expression, "in the front of muffle," is not intended to mean in the very front part of the muffle (for the muffle was never filled to its capacity, and the charges were always placed at the back), but, rather, nearest the front and in front of the row of Seger cones. The muffle was small ($11'' \times 7'' \times 5''$), and it was found that, at times, when the coke did not work down along its sides evenly or when the blast became partially choked at one point, there would often be as much as 50°C . difference in a distance of 6". This cooling occurred almost always in the front of the muffle, because at this point most difficulty was encountered in keeping the coke packed, due to the fact that the muffles were sunk into the brick work of the furnace about 8", making it very hard to use a poker effectively. Then, too, the front part of the fire-box was the most troublesome part of the furnace to keep free from accretions. Thus the front of the muffle was almost always cooler than the back part.

CaCO_3 , in place of CaO , was used in making up the cones, this being done to avoid the slaking effects of the CaO , since the cones had to be made up wet, and it was feared that, upon drying, they would reabsorb CO_2 from

the air, expand, and crack. In the crucible tests, however, the CaO was used, as these were to be dry tests, *i. e.*, tests on the dry mixtures. The latter tests were conducted at a temperature of 1410°C. (No. 14 Seger). The contents of the crucible was poured onto an iron plate, which was heated to about 300°C. and inclined at an angle of 7° 8". The flow was measured along this plate.

FUSIBILITY TESTS.

Slag No.	Cone No.	Temp. °C.	Slag** Char'ct'r	Slag No.	Cone No.	Temp. °C.	Slag** Char'ct'r
1	1	1295*	h	6	3	1270*	g
1	2	1295*	h	6	4	1270*	g
1	3	1290*	h	6	5	1270*	b
1	4	1290*	h	6	6	1270*	b
1	5	1290*	h	7	1	1320*	a
1	6	1290*	h	7	2	1320*	a
2	1	1300*	i	7	3	1270*	e
2	2	1300*	i	7	4	1270*	e
2	3	1305*	i	7	5	1330*	g
2	4	1305*	i	7	6	1330*	g
2	5	1300*	i	8	1	1310*	l
2	6	1300*	i	8	2	1330*	l
3	1	1290*	b	8	3	1320*	l
3	2	1295*	b	8	4		
3	3	1260*	b	8	5		
3	4	1260*	b	8	6		
3	5	1300*	b	9	1	1305*	l
3	6	1300*	b	9	2	1315*	l
4	1	1295	b	9	3	1295*	q
4	2	1300	b	9	4	1300*	q
4	3	1280	b	9	5		
4	4		b	9	6		
4	5	1290	b	10	1	1270*	q
4	6	1290	b	10	2	1270*	q
5	1	1282	e	10	3	1330*	k
5	2	1292*	e	10	4	1330*	k
5	3	1280*	e	10	5		
5	4	1280*	e	10	6		
5	5	1305*	e	11	1	1330	g
5	6	1320*	e	11	2	1330	g
6	1	1300*	g	11	3	1270	x
6	2	1320*	g	11	4	1270	x

*Temperature taken by Le Chatelier's pyrometer. All temperature readings not marked * were taken by means of Seger's cones.

**Description of Slag Character: (a) earthy, (b) resinous, (c) quite resinous, (d) resinous and scoreaceous, (e) vitreous, (f) quite vitreous, (g) slightly vitreous, (h) vitreous and scoraceous, (i) vitreous and scoreaceous: less brilliant than slag No. 1, (j) slightly vitreous and scoreaceous, (k) stony, (l) stony and slightly porous, (m) stony and dense, (n) stony and white, (o) stony, dense and light colored, (p) slightly vitreous and tough, (q) slightly vitreous and porous, (r) vitreous and dense, (s) vitreous and dark, (t) vitreous and brown, (u) slightly vitreous and dense, (v) glassy, (w) slightly glassy, (x) glassy and clear, (y) glassy and greenish, (z) like quartzite.

Slag No.	Cone No.	Temp. °C.	Slag** Char'ct'r	Slag No.	Cone No.	Temp. °C.	Slag** Char'ct'r
11	5	1270	x	19	5	1270	p
11	6	1270	a	19	6	1270	p
12	1	1310	g	20	1	1310	r
12	2	1310	g	20	2	1310	r
12	3	1310	x	20	3	1270 ²	r
12	4	1310	x	20	4	1270 ²	r
12	5	1290	a	20	5	1270 ²	r
12	6	1290	a	20	6	1270 ²	r
13	1	1270	e	21	1	1290	r
13	2	1310	e	21	2	1290	r
13	3	1270	d	21	3	1270 ²	r
13	4	1270	d	21	4	1270 ²	r
13	5	1270	c	21	5	1270 ²	r
13	6	1270	c	21	6	1270 ²	r
14	1	1290	e	22	1	1290	v
14	2	1290	e	22	2	1290	v
14	3	1270	g	22	3	1330 ³	g
14	4	1270	g	22	4	1350 ³	g
14	5	1310	c	22	5	1270	w
14	6	1290	c	22	6	1270	w
15	1	1332*	m	23	1	1310 ³	g
15	2	1352*	m	23	2	1310 ³	g
15	3	1350*	m	23	3	1270	w
15	4	1350*	m	23	4	1270	w
15	5 ¹			23	5	1270	g
15	6 ¹			23	6	1270	g
16	1	1290	v	24	1	1310	z
16	2	1290	v	24	2	1290	z
16	3	1290	w	24	3	1290	z
16	4	1290	w	24	4	1290	z
16	5	1290	v	24	5	1270 ⁴	z
16	6	1290	v	24	6	1270 ⁴	z
17	1	1310	k	25	1	1290 ³	a
17	2	1310	k	25	2	1290 ³	a
17	3	1290	u	25	3	1290	z
17	4	1290	u	25	4	1290	z
17	5	1270 ²	z	25	5	1290	z
17	6	1270 ²	z	25	6	1290	z
18	1	1310 ²	k	26	1	1290 ³	a
18	2	1310	k	26	2	1290 ³	a
18	3	1270	m	26	3	1290 ³	a
18	4	1270	m	26	4	1290 ³	a
18	5	1290	u	26	5	1290	z
18	6	1290	m	26	6	1290	z
19	1	1270	j	27	1	1290 ³	a
19	2	1270	j	27	2	1290 ³	a
19	3	1290	j	27	3	1290 ³	a
19	4	1290	j	27	4	1290 ³	a

¹Cone broke.²High initial temperature, and Seger's cones did not respond rapidly enough to obtain an accurate reading.³In front of muffle.⁴High initial temperature.

Slag No.	Cone No.	Temp. °C.	Slag** Char'ct'r	Slag No.	Cone No.	Temp. °C.	Slag** Char'ct'r
27	5	1290	g	36	1	1290 ³	g
27	6	1290	g	36	2	1310 ³	g
28	1	1290	k	36	3	1290	r
28	2	1290	k	36	4	1290	r
28	3	1290	k	36	5	1290	v
28	4	1290	k	36	6	1290	v
28	5	1270	k	37	1	1290	s
28	6	1290	k	37	2	1290	s
29	1	1310 ³	a	37	3	1270	r
29	2	1310 ³	a	37	4	1270	r
29	3	1290	v	37	5	1270	s
29	4	1290	v	37	6	1270	s
29	5	1290	k	38	1	1290 ³	a
29	6	1290	k	38	2	1290 ³	a
30	1	1310 ³	a	38	3	1270	z
30	2	1310 ³	a	38	4	1270	z
30	3	1290	u	38	5	1270	z
30	4	1290	u	38	6	1270	z
30	5	1270	k	39	1	1290 ³	a
30	6	1290	k	39	2	1290 ³	a
31	1	1290	k	39	3	1270	s
31	2	1290	k	39	4	1290	s
31	3	1290	a	39	5	1270	a
31	4	1290	a	39	6	1270	a
31	5	1270	k	40	1	1290 ³	a
31	6	1270	k	40	2	1290 ³	z
32	1	1310	u	40	3	1270 ³	a
32	2	1310	u	40	4	1290 ³	a
32	3	1290	k	40	5	1270	a
32	4	1290	k	40	6	1270	a
32	5	1270	v	41	1	1310	v
32	6	1270	v	41	2	1310	v
33	1	1310	r	41	3	1290	v
33	2	1310	r	41	4	1290	v
33	3	1290	a	41	5	1270	y
33	4	1290	k	41	6	1290	y
33	5	1290	v	42	1 ³	1310	y
33	6	1290	v	42	2 ³	1310	y
34	1	1290	r	42	3	1290	y
34	2	1290	r	42	4	1290	y
34	3	1290	s	42	5	1270	y
34	4	1290	s	42	6	1290	y
34	5	1290	b	43	1 ⁶	1310	y
34	6	1290	b	43	2 ⁶	1310	y
35	1	1310 ³	u	43	3	1290	k
35	2	1310 ³	k	43	4	1290	k
35	3	1310 ³	a	43	5	1290	b
35	4	1310 ³	a	43	6	1310	b
35	5	1290	z	44	1 ⁿ	1310	b
35	6	1290	z	44	2 ⁸	1310	b

³Went down unobserved, and when noticed, No. 9 Seger was just going (1310°C.).

⁶Went down unobserved; Seger No. 9 was going, when noticed.

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Slag No.	Cone No.	Temp. °C.	Slag** Char'ct'r	Slag No.	Cone No.	Temp. °C.	Slag** Char'ct'r
44	3	1290	k	53	1 ¹	1350	a
44	4	1290	k	53	2 ¹	1350	a
44	5	1290	b	53	3 ¹	1350	n
44	6	1290	b	53	4 ¹	1350	n
45	1	1310	g	53	5	1310	k
45	2	1310	g	53	6	1310	k
45	3	1310	a	54	1	1310	g
45	4	1310	a	54	2	1310	g
45	5	1310	b	54	3	1290	z
45	6	1310	b	54	4	1290	z
46	1	1310	g	54	5	1310	z
46	2	1310	g	54	6	1310	z
46	3	1290 ^s	a	55	1	1310	g
46	4	1290 ^s	a	55	2	1310	g
46	5	1310	g	55	3	1290	z
46	6	1310	g	55	4	1290	z
47	1	1310	k	55	5	1290	z
47	2	1310	k	55	6	1290	z
47	3	1350 ^s	z	56	1	1290	g
47	4	1350 ^s	z	56	2	1290	g
47	5	1310	k	56	3	1290	r
47	6	1310	k	56	4	1290	r
48	1	1330 ^s	a	56	5	1290	r
48	2	1330 ^s	a	56	6	1290	r
48	3	1290	k	57	1	1310	g
48	4	1290	k	57	2	1310	g
48	5	1290	b	57	3	1290	e
48	6	1290	b	57	4	1290	e
49	1	1330 ^s	a	57	5	1290	t
49	2	1330 ^s	a	57	6	1290	t
49	3	1290	g	58	1	1330	g
49	4	1290	g	58	2	1330	g
49	5	1290	e	58	3	1390	t
49	6	1290	e	58	4	1290	t
50	1	1330 ^s	a	58	5	1290	t
50	2	1350 ^s	a	58	6	1290	t
50	3	1290	f	59	1	1330	n
50	4	1290	f	59	2	1330	n
50	5	1290	g	59	3	1290	z
50	6	1290	g	59	4	1290	z
51	1	1290	f	59	5	1310	a
51	2	1290	f	59	6	1310	a
51	3	1290	f	60	1	1330	a
51	4	1290	f	60	2	1330	a
51	5	1310	v	60	3	1310	a
51	6	1310	v	60	4	1310	a
52	1	1290	b	60	5	1310	a
52	2	1290	b	60	6	1310	a
52	3	1290	b	61	1	1290	a
52	4	1290	b	61	2	1290	a
52	5	1310	b	61	3	1310	o
52	6	1310	b	61	4	1310	o

^sOnly slightly melted.

Slag No.	Cone No.	Temp. °C.	Slag** Char'ct'r	Slag No.	Cone No.	Temp. °C.	Slag** Char'ct'r
61	5	1290	r	63	6	1310	a
61	6	1290	r	64	1	1310	o
62	1	1310	o	64	2	1310	o
62	2	1310	o	64	3	1290	m
62	3	1290	r	64	4	1290	m
62	4	1290	r	64	5	1310	a
62	5	1310	a	64	6	1310	a
62	6	1310	a	1 ^a	1	1290	
63	1	1310	o	1 ^a	2	1290	
63	2	1310	o	1 ^b	1	1290	
63	3	1290	m	1 ^b	2	1290	
63	4	1290	m	2 ^b	1	1310	
63	5	1310	a	2 ^b	2	1310	

FLUIDITY TESTS.

Slag

No.

Slag Character.

- 1.....Glassy, white, and very viscous.
- 2.....Glassy, white, and very viscous.
- 3.....Brown mottled glass; flowed $1\frac{1}{4}$ ".
- 4.....Light brown, muddy, mottled glass; flowed $1\frac{1}{2}$ ".
- 5.....Light brown, mottled glass; flowed $1\frac{1}{16}$ ".
- 6.....Dark brown glass; flowed $2\frac{1}{4}$ ".
- 7.....Dark brown glass; flowed $2\frac{1}{4}$ ".
- 8.....Glassy, greenish, and very slightly fluid.
- 9.....Glassy, greenish, and very slightly fluid.
- 10.....Stony mass, would not flow.
- 11.....Glassy, but viscous.
- 12.....Glassy, but viscous.
- 13.....Glassy, but quite viscous.
- 14.....Glassy, but viscous.
- 15.....Would not flow; white, dead surface.
- 16.....Would not flow; white, dead surface.
- 17.....Glassy, vitreous and milky, also viscous.
- 18.....Glassy, vitreous and dirty, also viscous.
- 19.....Very viscous, and having a light brown, glassy surface.
- 20.....Grayish glass, very viscous.
- 21.....Viscous, glassy, and brown.
- 22.....Would not flow; gray, dead surface.
- 23.....Greenish glass, and viscous.
- 24.....Brownish glass, and viscous.
- 25.....Glassy, milky, and viscous.
- 26.....Dark brown glass; flowed $1\frac{3}{4}$ ".
- 27.....Dark brown glass; flowed $2\frac{1}{16}$ ".
- 28.....Dark brown glass; flowed $1\frac{12}{16}$ ".
- 29.....Very light brown glass, slightly mottled; flowed $1\frac{3}{8}$ ".
- 30.....Brown, mottled glass; flowed $1\frac{3}{4}$ ".
- 31.....Brown, mottled glass; flowed $1\frac{3}{8}$ ".

Made in nickel crucibles and taken out immediately upon reaching 1410°C. The slags Nos. 13 and 14 were in front of muffle and may not have quite reached this temperature.

*Dark gray blast furnace slag from Jones & Laughlin Steel Co., Pittsburg, Pa.
 *Hoffman slags. The temperatures given here correspond exactly to those given by Mr. Hoffman.

Slag

No.	Slag Character.
32.....	Very viscous, gray and glassy.
33.....	Viscous, opaque, mottled, dark glass.
34.....	Black, mottled glass; flowed $1\frac{1}{4}$ ".
35.....	Did not flow; gray, earthy mass.
36.....	Did not flow; gray, earthy mass.
37.....	Very viscous, stony.
38.....	Viscous, mottled, greenish glass.
39.....	Viscous, mottled, opaque, dark glass.
40.....	Black glass; flowed $1\frac{3}{4}$ ".
41.....	Clear, light green glass; flowed $1\frac{1}{2}$ ".
42.....	Clear, light green glass; flowed $1\frac{1}{2}$ ".
43.....	Gray, opaque, mottled glass; flowed $1\frac{3}{8}$ ".
44.....	Gray, opaque, mottled glass; flowed $1\frac{1}{8}$ ".
45.....	Very dark glass; flowed 2".
46.....	Black, stony mass; flowed $2\frac{1}{4}$ ".
47.....	Would not flow; stony, gray mass.) In front of muffle.
48.....	Would not flow; stony, gray mass.)
49.....	Dark greenish, viscous glass.
50.....	Dark greenish, viscous glass.
51.....	Dark brown, opaque glass; flowed 1".
52.....	Dark brown, opaque glass; flowed 1".

Rossi Slags.

Slag

No.	Slag Character.
1.....	Gray, stony; flowed $1\frac{1}{2}$ ".
2.....	Black glass; flowed $2\frac{1}{4}$ ". (Scorified in crucible.)
3.....	Dark gray earthy mass; would not flow.
4.....	Black, stony mass, very viscous.

FLUIDITY TESTS ON TWO ACTUAL, GROUND BLAST FURNACE SLAGS.

Slag

No.	Slag Character.
1.....	Dark gray, basic slag, 20g.; would not pour, but blubbed in crucible.
2.....	Dark gray, basic slag, 40g.; very viscous, and blubbed.

CONCLUSIONS.

From a study of the fusion tests, it is noted that those cones with magnesia in them melted at a temperature slightly less, generally speaking, than any others. Also that those cones made up with lime and alumina, in the ratio 4:1, melted at temperatures slightly higher than any others. These differences, however, were slight, and since the fusion point of all the slags come within the range 1270°C. to 1350°C. (this being considerably below the ordinary blast furnace temperature), we consider ourselves justified in saying that no difficulty would be en-

countered in fusing any of these mixtures in the ordinary blast furnace, but their fluidity after fusion is a question still to be considered.

In these cone tests, very little, if any, real differences were found in the fusion points of the different silicates tested. The character of the slag was noted in each case, but this varies so largely with the location of the cones in the furnace, the time that they remained in (waiting for others of the same test to melt), and the temperature to which the furnace rose before they were removed, that it can give no real information in regard to the comparative merits of the slags.

An idea may be had of the accuracy with which the temperatures of fusion were taken by a glance at the work on Mr. Hoffman's silicates, which appears at the end of the record of Fusibility Tests.

From a study of the results obtained from the Fluidity tests, it is found that the monosilicates are the most fluid, the bisilicates and sesquisilicates quite viscous, and the trisilicates, containing the higher per cents. of TiO_2 , were somewhat fluid. Little difference was found in the slags made up with varying proportions of the bases. But it was found that the fluidity almost invariably increased with an increase in TiO_2 . It should be noted that with an increase of TiO_2 , there was also an increase in the FeO present. In no case were the comparison slags found to be more fluid than our own. Thus since these comparison slags have proved to be all that is required of a blast furnace slag, we see no reason why the more fluid at least of our slags, might not be used successfully in the blast furnace. Of course, it was impossible to judge accurately, from the small charges that were used, what would be the action of large masses of the slag. In our case the small quantity of intensely hot material was bound to chill very quickly upon coming in contact with the air, and then, to add to this, the hot plate we used was heated by gas, and 300°C . was about as hot as it could be kept, so that it was cold to the slag.

Our main object in performing these experiments was, if possible, to prove that TiO_2 in an ore, if properly

handled, is no great detriment. There is good authority for the statement that blast furnaces have been run advantageously on ores containing as high as 5 % TiO_2 .

Our experiments have shown that the fluidity of our slags increases with the increase in the per cent. of titanitic acid, and we, therefore, believe that TiO_2 in moderate quantity in ore, if properly handled in a blast furnace, will give less trouble than heretofore supposed.

In conclusion, we desire to thank Professor F. Crabtree, of the Department of Mining and Metallurgy, and Professor William Strieby, of the Department of Chemistry, for criticisms and numerous suggestions.

THE DESIGN OF A LOW-TENSION SWITCH-BOARD.*

BY VERNON T. BRIGHAM.

INTRODUCTORY NOTE.

The problem of a convenient intercommunicating switchboard is of interest to all workers in Physics and Electrical Engineering. During the past two years this problem has received attention in connection with the equipping of the laboratories of Colorado College. This study has resulted in a working switchboard, as described in the following paper.

Switchboards may be divided into two classes, the first being one in which a "knife," or "stab," switch is used to close the circuit. The second is the usual cord-plug board so frequently found. The first type is suitable only for fixed connections, and cannot readily be made into an intercommunicating board. The second type is objectionable from the fact that short circuits can easily be blundered into, and are continually being made by inexperienced students. It is also limited in that it is difficult to provide for a large number of parallel connections to power circuits. The appearance of such a board when connected up with a dozen or more circuits is somewhat bewildering. From the standpoint of appearance when in use, the board is not to be commended.

The advantages sought in the present design are: Simplicity in the making and breaking of circuits, protection from possible short circuits on the board, independence in making as many parallel power connections as desired, and a neat appearance.

In undertaking the work, a preliminary study of switchboards was made, and helpful ideas were gained from several sources. In particular, acknowledgements are due to Professor Henry Crew and Dr. R. R. Tatnall,

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of Northwestern University, and to Mr. C. O. Poole, of Denver, for helpful suggestions in the early stages of the design; also to Dr. Robert Hartmann-Kempf, of Francfort-on-Main, Germany.—*John C. Shedd, Professor of Physics.*

The general scheme of this switchboard is to run the power and series circuits horizontally and the distributing circuits vertically. Then, by suitable contacts sliding on the distributing circuit conductors, connection is made at the intersection of a positive horizontal with a positive vertical, and a negative horizontal with a negative vertical conductor, whereby a completed circuit is made.

The advantages sought after in this type of switchboard are as follows: Protection against fire, strength, high insulation, the use throughout of the sliding contact and the complete elimination of the cord and plug circuits, good contact, economy in the use of copper, ease and simplicity in the making and breaking of circuits, the simplicity of the parts, automatic self-protection, the easy removal and renewal of parts, a presentable appearance, and compactness.

All materials used were chosen primarily from the consideration of their fire-resisting qualities, and secondarily from the consideration of their resistance, conductance, and strength.

The materials selected were steel, slate, copper, brass, micanite and fibre.

The frame shown in Plate I was constructed of steel, in the form of a truss, and designed to carry a load of 650 pounds over a span of 9 feet, center to center of the columns. The respective weights of the materials are as follows: Iron, 114 lbs; slate, 380 lb.; contacts, 56 lbs.; fibre and micanite, 50 lbs.; copper, 20 lbs.

The columns are constructed of 2"x2"x4.4 T-bars, the bottom and top rails of 2½"x2½"x3.1 angles, the braces of ½" round bars, and stiffeners of ⅝" round bars. From the table of Safe Loads for the Angles Chosen, page 190, Cambria, it is found that the safe load is 700 lbs., but the deflection would be about 0.3", which is too great. The steel rod brace was designed to

carry one-half the total load at the center of the truss, thus reducing the deflection to a minimum. The load carried by the brace is 325 lbs. The angle which it makes with the horizontal is 33° . Then the tension on each rod is $\frac{1}{2}$ of $325/\sin 33^{\circ} = 301$ lbs. The safe working stress of the threaded joint is 800 lbs., which furnishes a large margin of strength.

Another part of the design where the consideration of the strength was of importance, which a clearer understanding of the operation of the switchboard will show, was in the slate guides, shown on Plate II. They must be capable of being very rigidly screwed to the frame, and must withstand the outward thrust of the movable contacts when the circuit is being closed, and the jar of the contact when falling.

The following results were obtained by actual test on a Riehle testing machine. The transverse breaking stress over a span of 31", or the distance, center to center, between the end screw holes:

EDGEWISE.

Test No. 1	570 lbs.
Test No. 2	550 lbs.
Test No. 3	270 lbs.

FLATWISE.

Test No. 1	110 lbs.
Test No. 2	90 lbs.
Test No. 3	75 lbs.

The longitudinal stress sustained by the end screw holes:

Test No. 1	290 lbs.
Test No. 2	310 lbs.

The force necessary to produce fracture of two slates in the working position, due to the outward thrust of the movable carriage:

Test No. 1	560 lbs.
Test No. 2	600 lbs.

The results show conclusively a great factor of safety within the slates.

High insulation was obtained by covering all stationary exposed conductors with an insulating material, and

by providing separate channels of insulating material for the movable parts to operate in. These channels are constructed so as to leave no straight lines between exposed points of opposite polarity, thus making impossible a short circuit by placing metal on the face of the board.

The advantage of the elimination of the plug-and-cord circuit is obvious.

Good contact is obtained and preserved by the sliding under pressure of one piece of metal over another, keeping the surfaces bright, and the wear of frequent use tending to produce a greater and more perfect contact surface.

The great economy in the use of copper was made possible by the bending, as shown in Plate III. There are no holes bored through the copper to diminish its conducting area. The absence of holes and the simplicity of the bending make that part of the construction quite simple.

The mode of construction and operation may be best considered by the aid of the accompanying diagrams. Plate I shows the steel frame, which has already been described. Plate II. shows the insulating guides, of which there are 99 on the board. These might properly be called the frame work to the operating parts of the board. They serve the several purposes of insulation between circuits and sliding contacts, and support for the power circuits, release plugs, setting points and indicating scales. These are constructed of slate bars $\frac{1}{2}$ " x $2\frac{1}{4}$ " x 32", with slots $\frac{1}{8}$ " wide and $\frac{1}{8}$ " deep, cut in both sides $\frac{1}{2}$ " from one edge, forming the head to the slate, in which are bored shallow tapered holes, which may be called the setting points, and will later be referred to. In the body of the slate are the release plugs, which are $\frac{1}{2}$ " x $\frac{1}{8}$ " round steel plugs, cemented in the slate with shellac, and projecting $\frac{1}{8}$ " from the surface. The slate body contains the screw holes and nuts by which means the spacing strip shown may be securely screwed to the slate. The screw holes are $\frac{3}{16}$ ", drilled in the bottom of the slate, and the nuts are set with putty in $\frac{5}{16}$ " holes, drilled in from the side of the slate to meet the screw holes.

These slates are placed alternately right and left $\frac{1}{2}$ " apart and secured to the steel framework by means of the top and bottom screw holes. The right and left arrangement of the slates permits the right or left contacts of a distributing circuit to operate upon but one side of any of the power circuits.

The spacing bars are constructed of fibre strips $\frac{1}{2}$ " x $\frac{5}{8}$ ", with slots cut in one side, as shown. They serve the double purpose of spacing and binding the copper busses firmly to the slate.

The slate spacing bar serves to hold the slates parallel, and in it are cut the slots which guide the motion of the conductor rods.

The conductor rods are made of $\frac{1}{4}$ " hollow brass tube, 36" in length. On these slide the movable contacts, which clutch the rod whenever a circuit is being made. The positive and negative conductor rods, which make up a circuit, are held together at the bottom by a fibre block, in the manner shown. To the top ends of these rods are soldered knife edges which, when pushed upwards by means of the block, enter clips which are fastened to the clip base, which in turn is bolted to the steel frame, in the manner shown in Plate III. On this plate is also shown a portion of the micanite insulating sheet. This sheet, in sections, is placed just under the slate. The loops of the copper ribbon are pressed into the square perforations and project inward between the slates. The top surface of the loops forms the conducting surface of the copper buss. The straight ribbon is to increase the conductivity of the buss.

The movable contact is shown in detail in Plate IV. The successful operation of the switchboard depends largely upon the operation of this part of the mechanism. Its operation is best illustrated by means of Fig. 1 and Fig. 2. The idle position of the contact is at the lowest point of its motion. When a circuit is to be made, the right-hand contact is moved upward until its pointer is at the scale division, which is etched upon the edge of the slate, of the circuit desired. In this position the safety-pin of the moving contact enters the taper hole at the

center point. (Fig. 2.) The lever may now be pressed down. The contact shoe, which in the moving position slides $\frac{1}{8}$ " above the loops, is, by the movement of the lever, clutched to the conductor rod and dropped to a position a little lower than the top of the loop shown at b', in Fig. 1. The left movable contact of the circuit is likewise pushed up and set. The push block is then pushed upward. This motion, transmitted by means of the conductor rods, moves both contacts up, and forces them to slide upon the loops of the positive and negative sides of the desired circuit. This same movement also forces the knife edges at the top of the rods into the clips. The contact at the clips follows the contact at the shoe, and accordingly, when the push block is pressed downward, the circuit breaks at the clip, preventing the occurrence of a spark within the board. When the downward motion of the push block is continued, the shoulders on the contact shoes strike the releasing plugs, and the tension on the conductor rods starts an upward rolling motion to the levers, which the combined strain on the springs completes. The contacts being now free to slide, drop to the bottom of the slot.

The closer inspection of the action of the safety-pin will show how the board is automatically self-protected. The lever can neither be moved down from the upward position nor up from the downward position, except when the contact shoe is at the setting point, since in all other positions the motion of the lever upward or downward would be blocked by the safety-pin. Thus, when the contacts are made the lever cannot be forced up, which motion might create a destructive arc within the board.

Plate IV. shows the assembling of the parts. The micanite sheet is first put in position. The slates are then put on in front of the micanite sheet and screwed to the frame. The formed copper ribbons are then pressed into place from behind, after being covered with armature tape; the spacing bars are put in place and screwed to the slates, binding the whole firmly together. Then follows the installation of the contacts and clips, and finally the wiring.

The compactness is in evidence from the fact that 1,500 possible circuits require but 36 sq. ft. of surface area, or but 3.4 sq. in. to the circuit.

In closing, I desire to thank Professor J. C. Shedd, of the Physics Department; Professor J. R. Armstrong, of the Department of Electrical Engineering, and Mr. C. G. Collais, Superintendent of Mechanical Laboratories, for continued help in the design and construction of the switchboard.

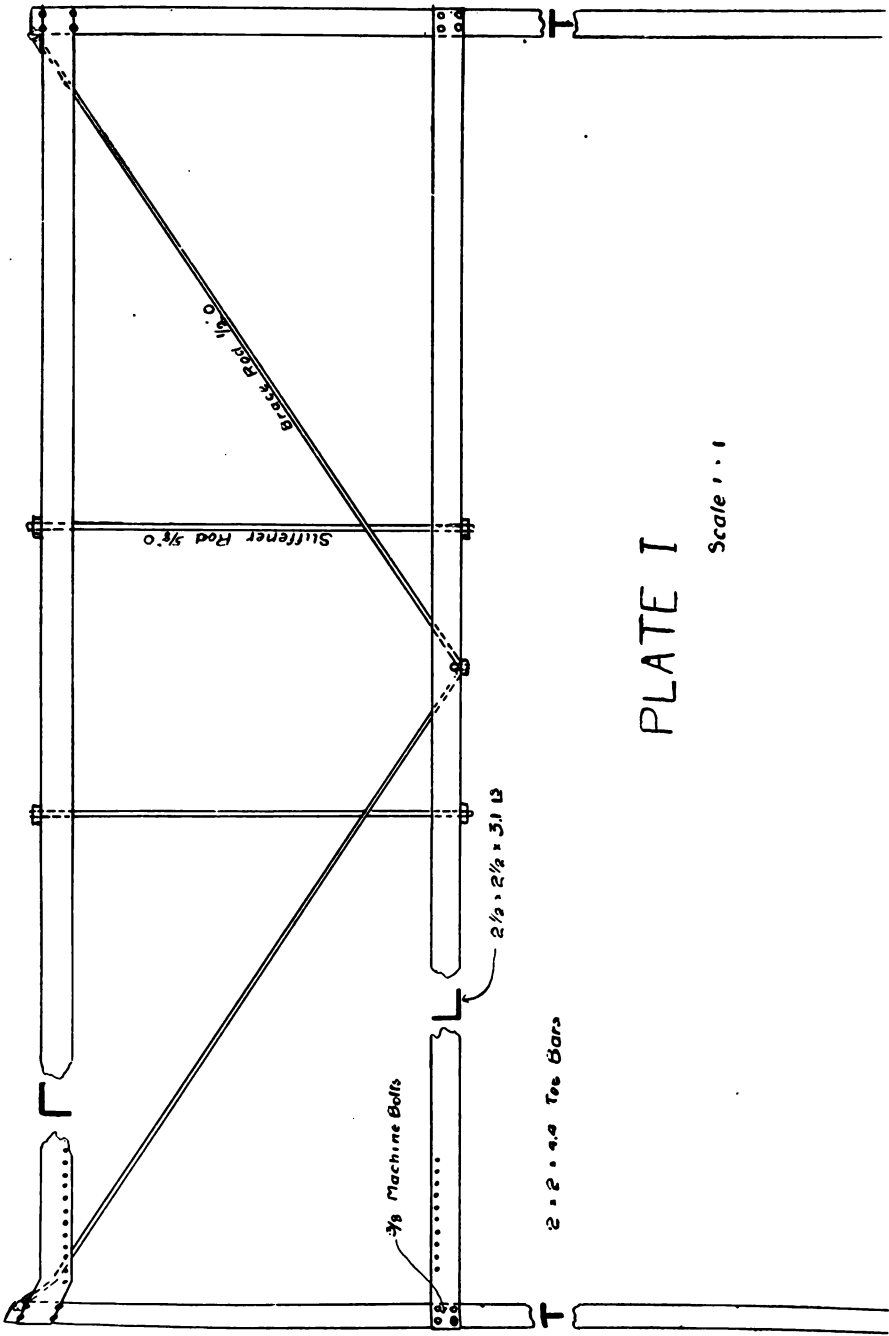
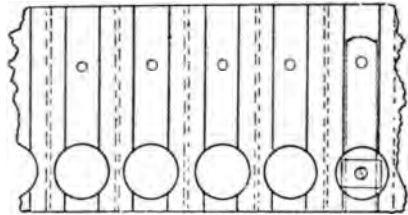
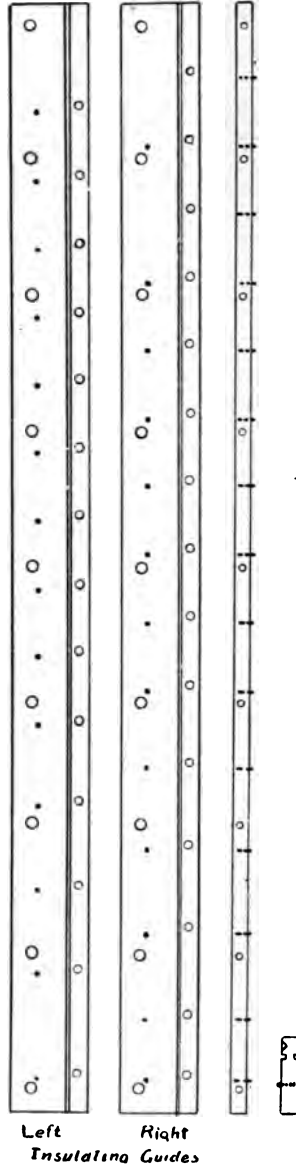
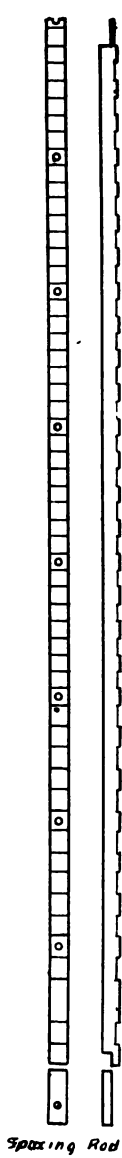


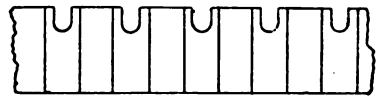
PLATE I

Scale 1 : 1

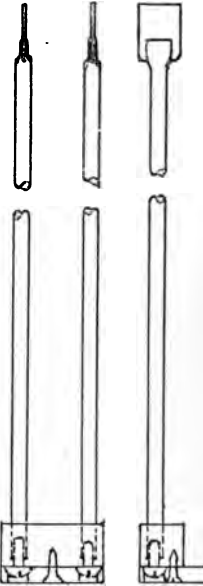
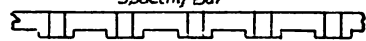


Clip Base

Scale 1:2



Spacing Bar



Conductor Rods

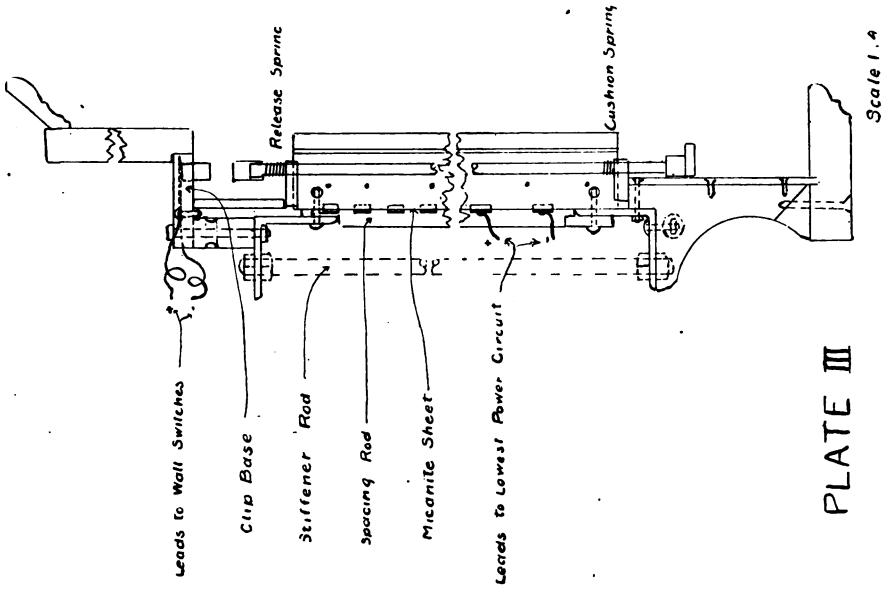


PLATE III

